Heavy Flavor Topical Group Plan

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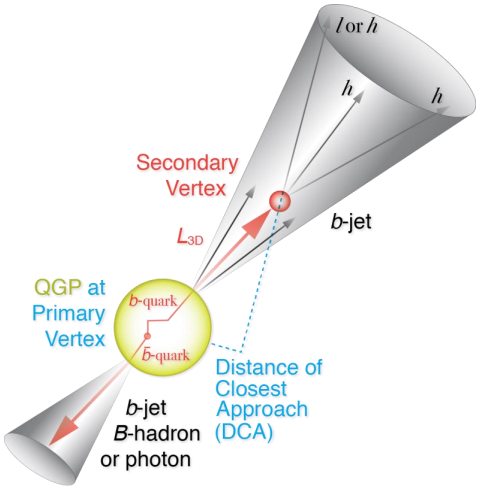
Jin Huang (BNL)

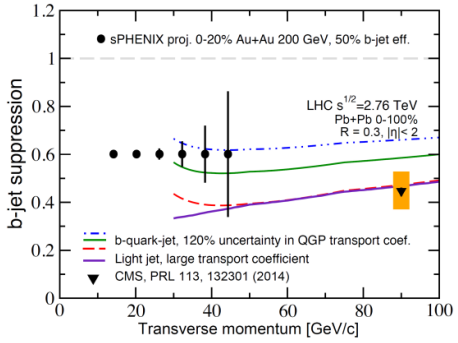
Special thanks to outgoing convener, Mike McCumber (LANL)

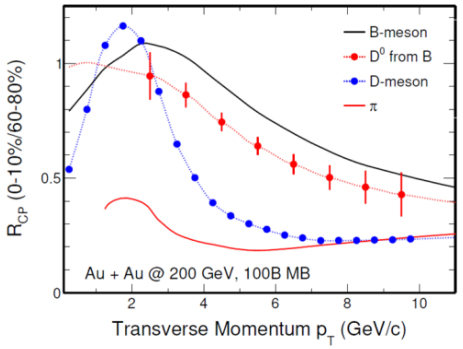
PHENIX

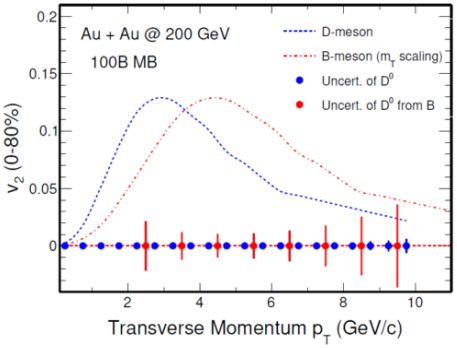
HF-topical group

- HF in sPHENIX: in particular B-meson and b-jets, provide differentiating sensitivity to collision VS radiative energy loss, access to HQ transport parameter of QGP, total cross section. Bring results to precision era.
  - *B*-meson: access down to zero pT, max sensitivity to HQ mass effect
  - *b*-Jet: less dependence on FF complication, probing parton kinematics and higher p_T-scale
- Topical group formed in Apr 2016 focusing on establishing b-jet program. Many progresses thanks to diligent team of developers. Delivered first Geant4-based b-jet tagging performance and expanding into correlation studies.
- In the new era of MVTX program, expanded the program in HF-meson program as initiated by LBNL and LANL groups, and serve the detector consortium of MVTX









- Communication:
  - Discussion email list: https://lists.bnl.gov/mailman/listinfo/sphenix-hf-jets-l
  - Wiki page under construction: https://wiki.bnl.gov/sPHENIX/index.php/Heavy_Flavor_Topical_Group
- Meetings/Events
  - Use weekly simulation meetings for updates, https://indico.bnl.gov/categoryDisplay.py?categId=88
  - Goal oriented irregular events:

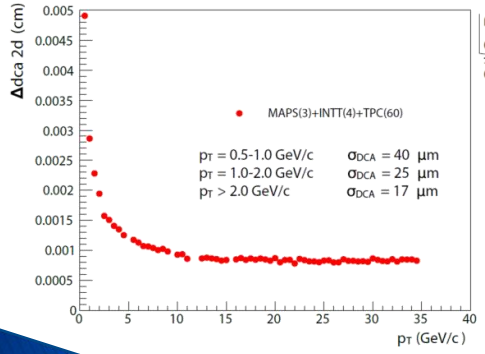
    MVTX brainstorming meeting, Mar 8 / MAPS+HF-jet joint workfests, e.g. Jan 5-7 2017 @ Santa Fe / Pre-collaboration meeting work-fest on May 16-17, 2016 / Initial TG meeting on Apr 22 , 2016
  - Expect new workfest between BNL director review on MVTX and full proposal to DOE

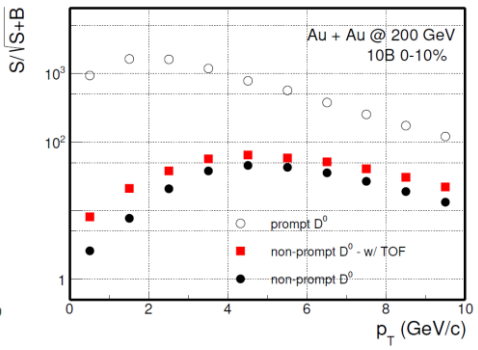
MVTX proposal TODO
Technical performances:

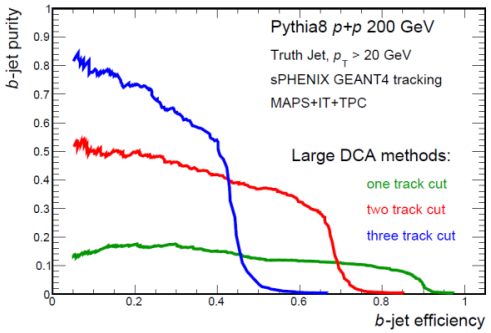
- Realistic implementation in Geant4
  - **Completed**: implement ladder structure in simulation – Tony F., Gaku M.
  - **Completed** : digitization of MAPS detector - Tony F.
  - **By end Apr**: Update tracking performance plots for MAPS, DCA and dp/p resolutiosn - Tony F.
  - **By summer (?)**: complete the pile-up simulation framework – Mike M., Yorito Y.
- *b*-jet tagging algorithm
  - **By summer, help needed** : Investigating full-detector fast simulation for b-jet simulation. Look into general packages e.g. DELPHES.
  - **By summer**: Full calorimetry simulation with secondary vertexing tagger – Sanghoon L.
  - **By summer**: Full calorimetry simulation with high-DCA track counting – Haiwang Y.
  - It will be very useful to use new in-development pattern recognition software to bring back hit collection efficiency.

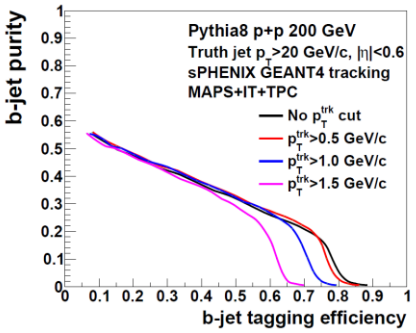
Updates

Updates









MVTX proposal TODO
Physics performances:

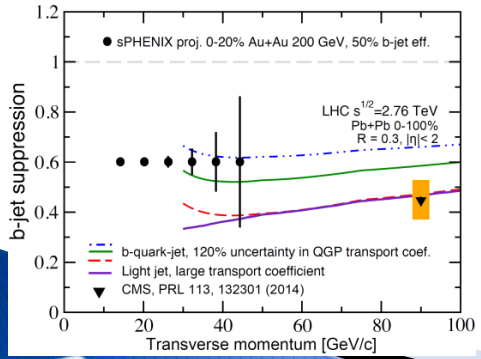
- Update non-prompt D meson performance projection
  - **Deliverable by end Apr** :update the Rcp and v2 plot with more realistic simulations for MB and peripheral collisions - Xin D., Xiaolong C.
- Explore complimentary B-hadron channels beyond non-prompt-D
  - **By summer**: Fast simulation for exclusive channels, B->J/Psi K, B->D pi - Xin D., Xiaolong C.
  - **By summer, help needed**: B->non-prompt J/Psi->e^+/e^- and p+p triggering
- Inclusive b-jet R_{AA}
  - **By Apr (?)**: Update theory curve to RHIC energy – Cesar da S. working with Vitev group
  - **Deliverable by end Apr**: Update theory curve for RHIC energy for R_{AA} plot

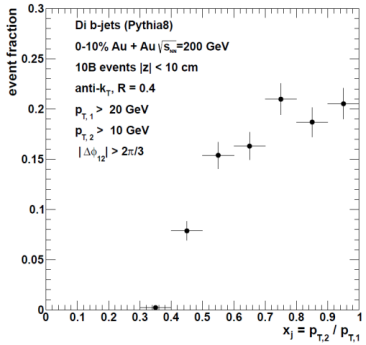
Updates

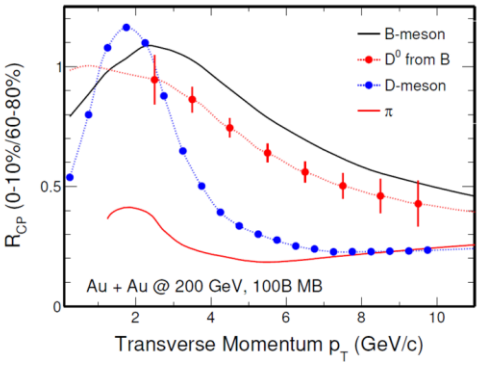
- di-b-jet asymmetry
  - **By Apr (on-going)**: Extract di-jet purity from Geant4 simulation - Haiwang Y.
  - **Deliverable by end Apr**: Apply di-jet purity to projection – Darren M., Haiwang Y.

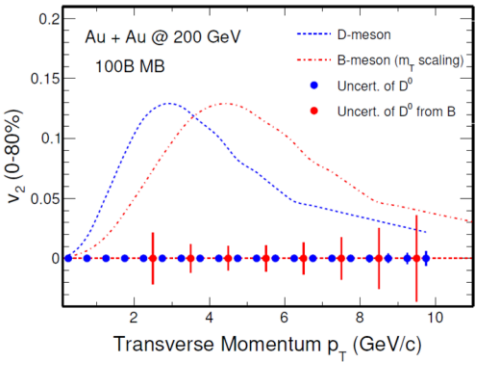
Updates

- b-jet-non-prompt-D asymmetry:
  - **Deliverable by end Apr (recently updated)**: Produce uncertainty projection in fast simulation – Xuan L.







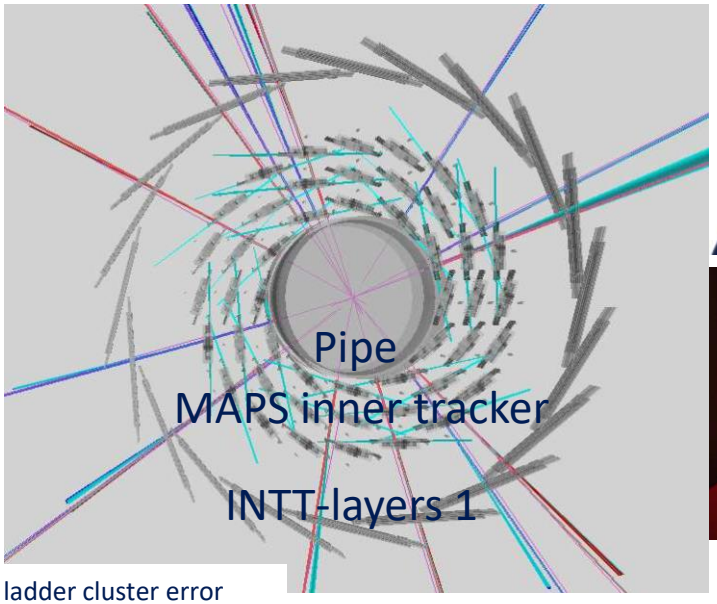


Additional study wish list
Help (always) wanted

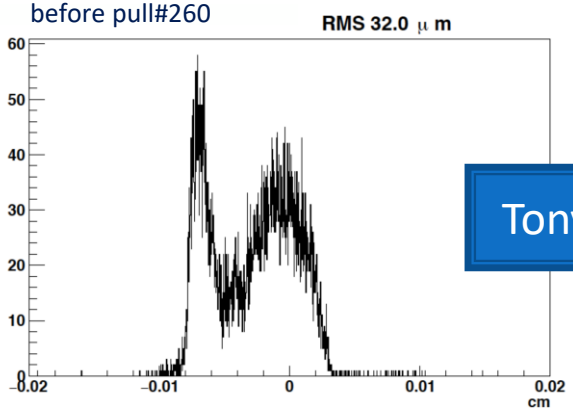
- **HF-hadron chemistry:** e.g. high stat. Λ_c, to study HQ hadronization
- **HF-meson correlations**, e.g. D-D_bar azimuthal correlations, to enhance sensitivity to HQ-medium interaction; enhance M/pT ratio scale comparing to D-b-jet correlation.
- Explore **b-jet substructure tools**:
  - Exercise jet-grooming algorithm, FF. – in collaboration with Jet Structure group
  - Tagging gluon splitting via multi-decay vertex in inclusive b-jets.
- Explore **Charmed-quark jet**:
  - charm fragmentation, completes mass hierarchy. Select D meson formed late in formation
  - Try out prompt-D tagger (ALI-PREL-117896) and Corrected Secondary vertex (arXiv:1612.08972)
- Explore **tagged D-meson in correlation with opposite hard structure**
  - Tagging initial c-quark kinematics with correlations, including D-meson - jet correlation and D-meson - photon correlation
  - Study D-FF and formation of D-meson
- Further **b-jet tagging developments**
  - Try different strategy: Soft-lepton tagging
  - Optimize analysis methods: likelihood analysis and machine learning tool
- **Triggering** of B-mesons in p+p collisions
  - B->J/Psi ->e+/e-, EMCal trigger. Exploration work by Sasha L.
  - D meson calorimetry trigger, turn on.
  - Large DCA triggers?

Progresses since last general meeting – modeling of silicon trackers

- Tracking software team finalizing ladder modeling
- Tony Frawley & Gaku Mitsuka:
  After implementing MAPS digitization, fixed a Geant-related INTT digitization problem:
  https://github.com/sPHENIX-Collaboration/coresoftware/pull/260
- Next – update DCA and momentum resolution plots for MVTX proposal

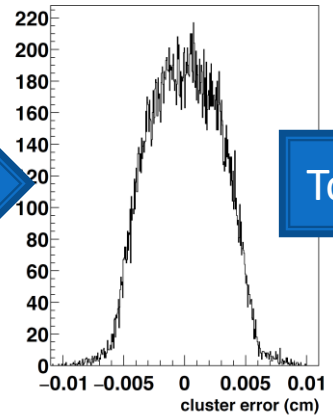


INTT ladder cluster error
before pull#260



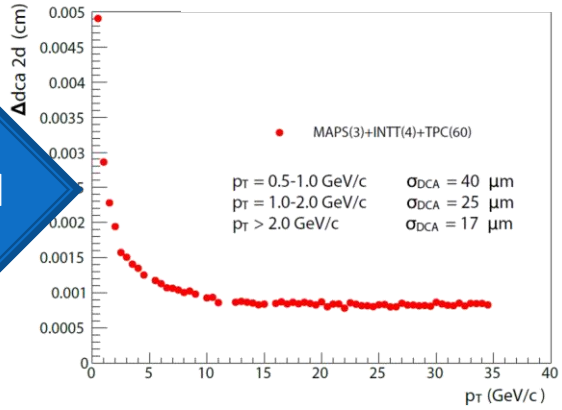
Tony's fix

INTT ladder cluster error
After pull#260 (RMS=29μm)

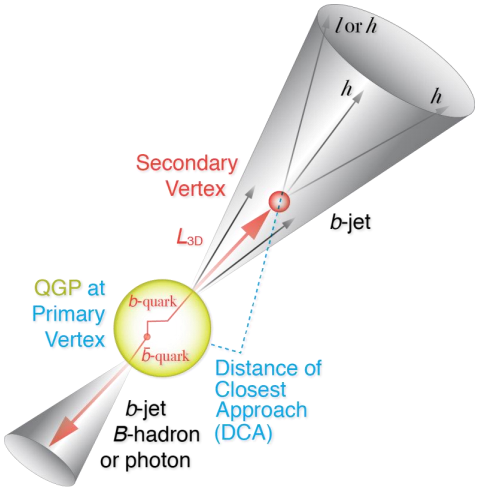


To be updated

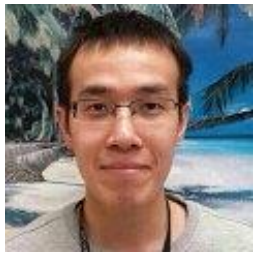
Previous DCA resolution curve
(with cylindrical tracker model)



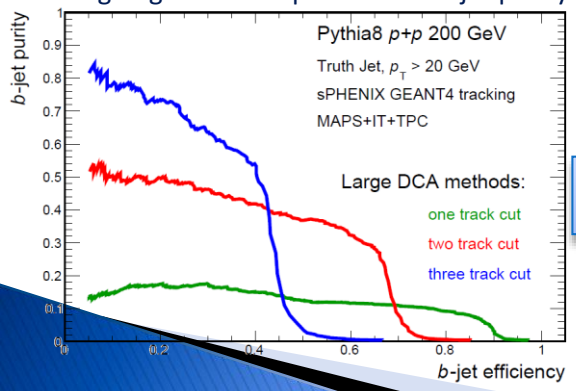
On-going since last general meeting – di-b-jet purity



- di-b-jet : one step beyond simple R_{AA}, probing jet-by-jet variation in energy loss, additional handle on initial b-pair production rate and kinematics
- Delivered: Darren produced di-b-jet pT-balance projection assuming perfect purity
- On-going: Haiwang working on producing Geant4-simulated di-b-jet asymmetry. To be updated next Tue simulation meeting
- Next^2: update di-b-jet p_T-balance projection and add model curves

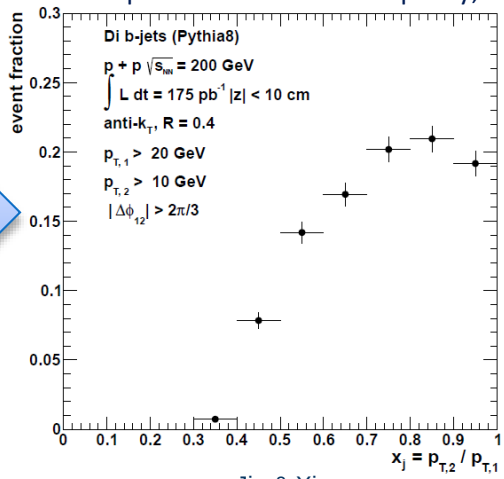


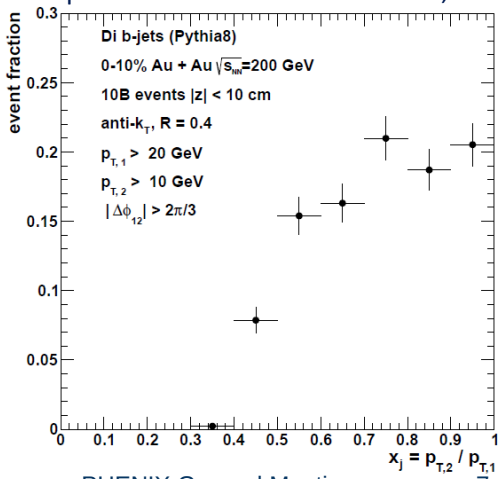
Purity VS efficiency for single jet
Ongoing work to reproduce to di-jet purity



To be updated and applied

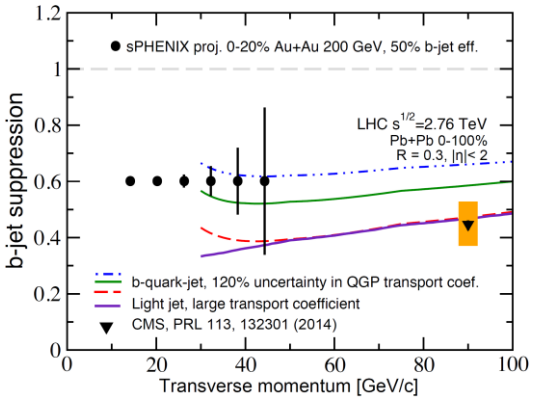
Di-b-jet transverse momentum balance projected with 50% eff. 100% purity
To be updated with simulated purity; also requested model curves from Ivan, etc.



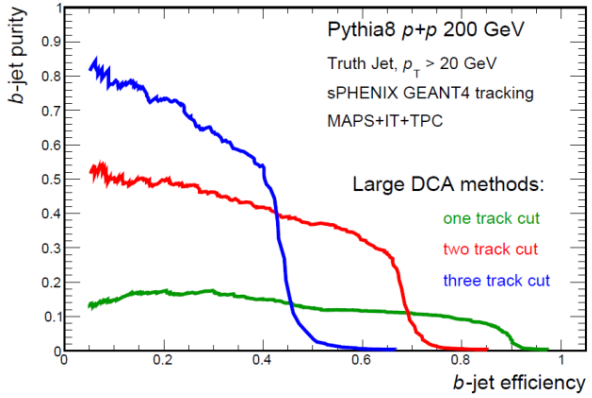


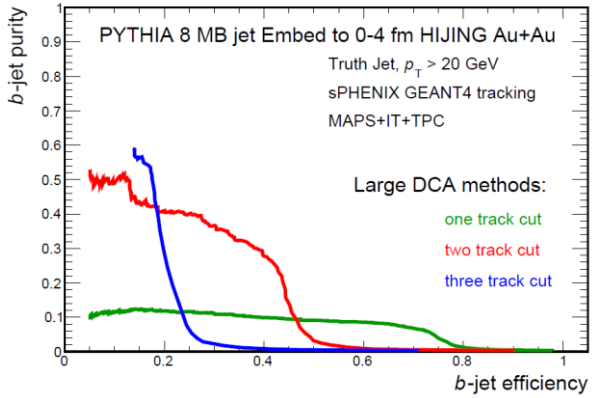
Extra information

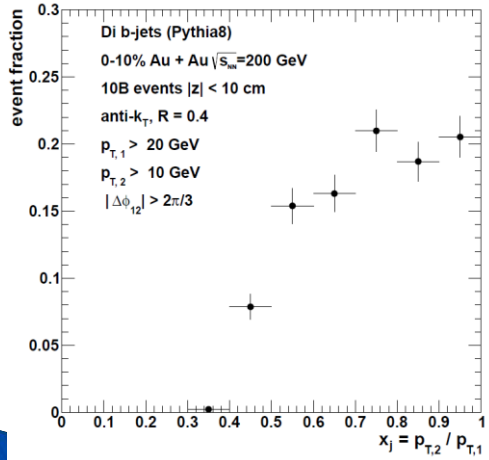
Delivered plots – HF-jet for Feb-2017 MAPS pre-proposal

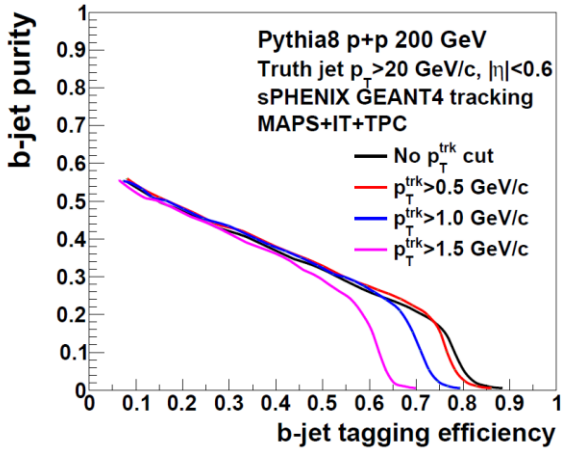


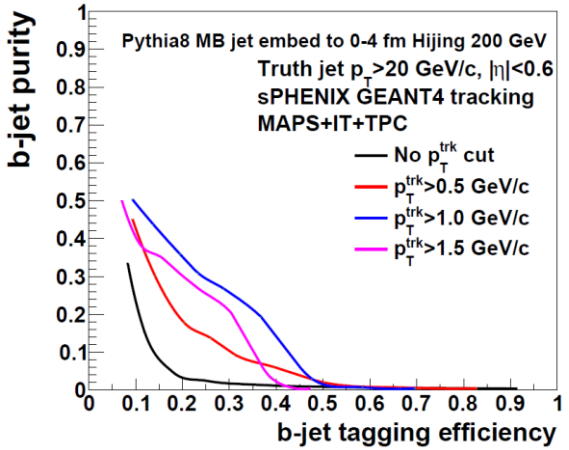
Curve update request, not yet received











Observable Projections

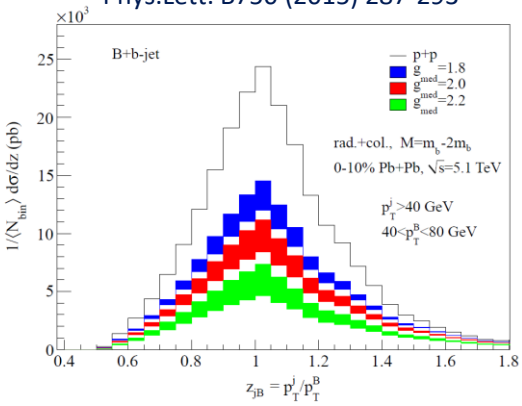
B-jet tagging in p+p

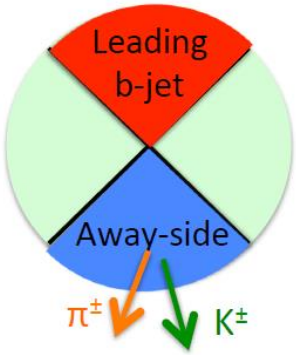
B-jet tagging in 10%C Au+Au

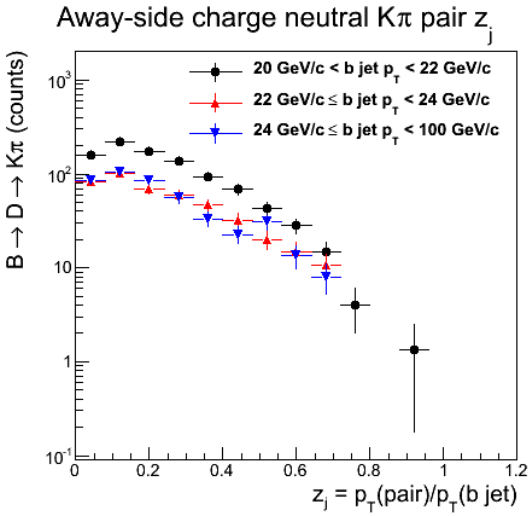
Progresses since brain storming meeting
Non-prompt D-meson correlations

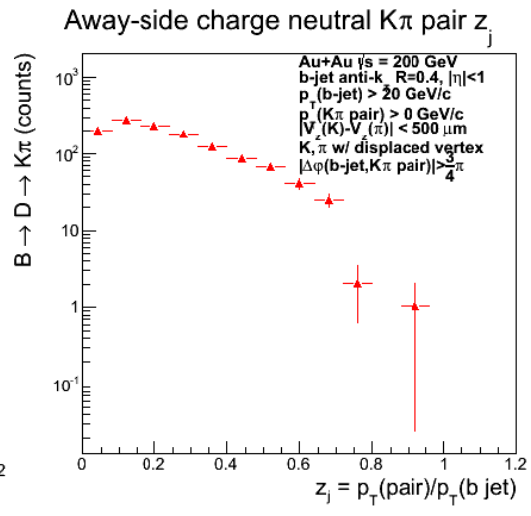
- Xuan Li (LANL) also started investigation of correlation of b-jet in correlation of a non-prompt D_0-meson (→pi + K)
- Goal: tag initial quark energy + vector for non-prompt D measurements, probe b-quark energy loss and fragmentation; access to lower z_j cut-off comparing to di-b-jets correlation; help purity of b-quark-jet tagging
- Producing fast simulation results for pre-proposal

Phys.Lett. B750 (2015) 287-293







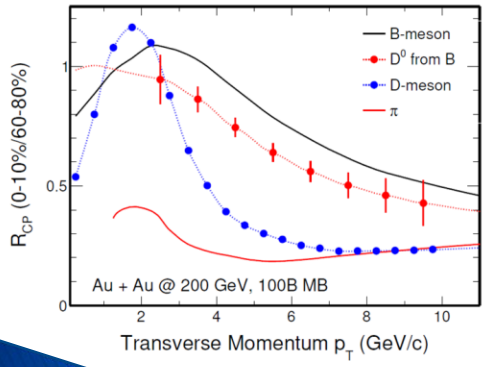


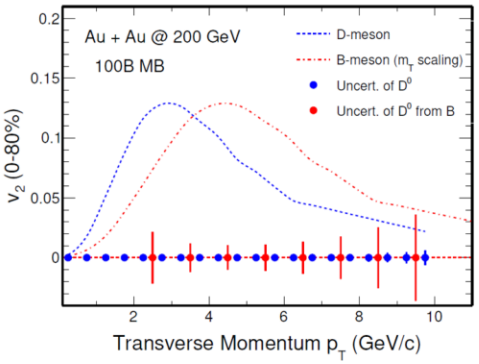
Updates in simulation meetings:
https://indico.bnl.gov/conferenceDisplay.py?confId=2684

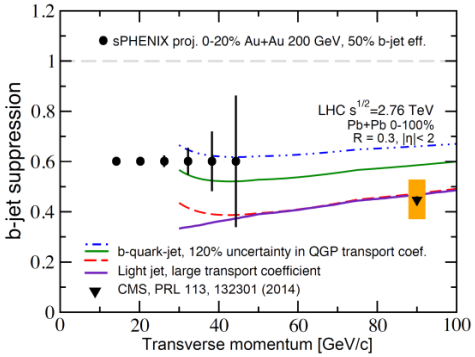
Preliminary study, in verification

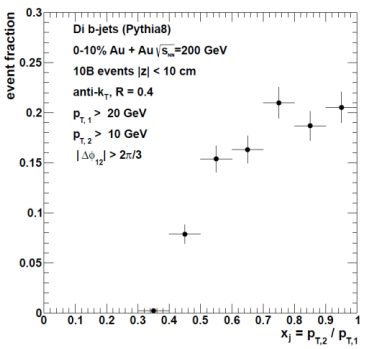
Path forward: summary

- Apr review/preproposal: Solidifying results and studies started preparing for thesFeb-2017 pre-proposal
- Summer review/full proposal:
  - Expansion of selected topics: more realistic simulation, exclusive B-meson reconstruction
  - Addressing BNL-charged review comments
  - Many more HF capabilities need your help to develop
- Expect workfest around time of May collaboration meeting







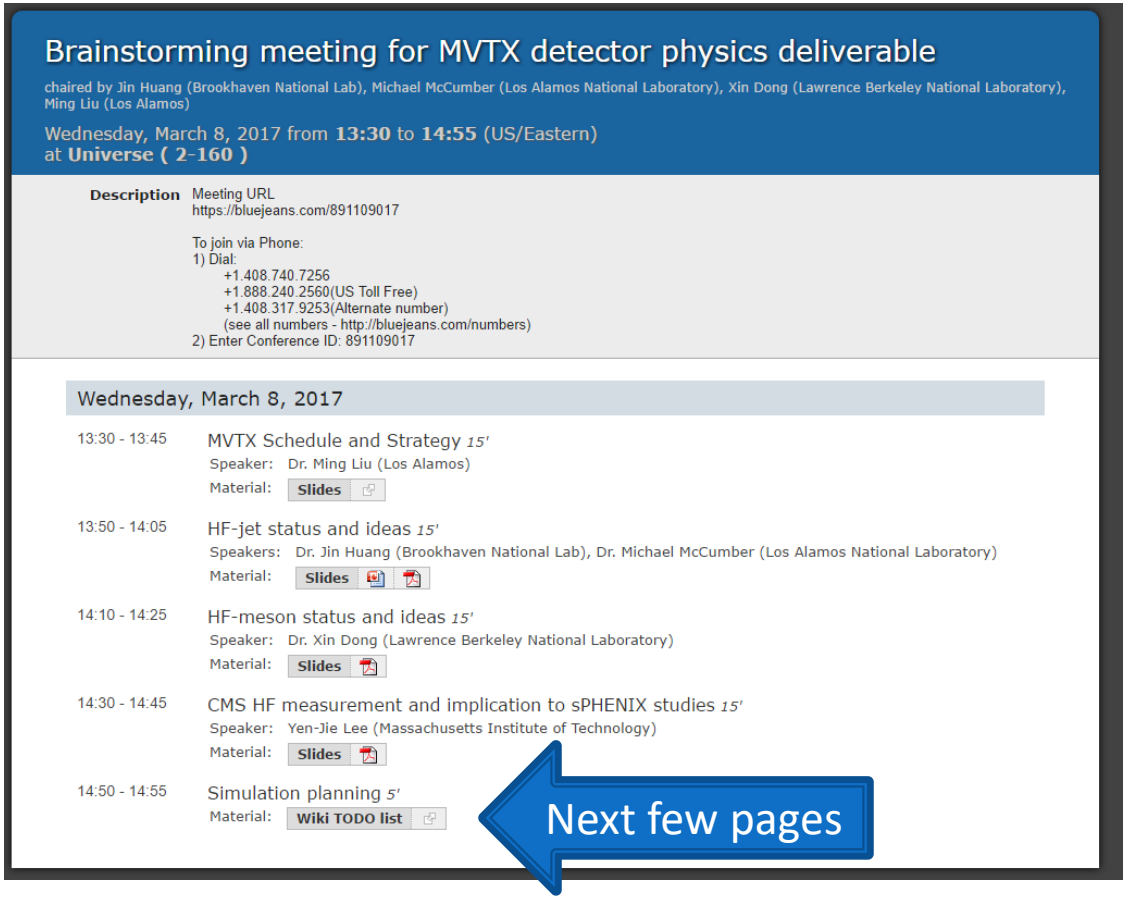


Brainstorming meeting, Mar 8

- https://indico.bnl.gov/conferenceDisplay.py?confId=2932
- About 20 sPHENIX collaborator and Ivan Vitev called in the discussion

Current development planning assumed two time-scale:

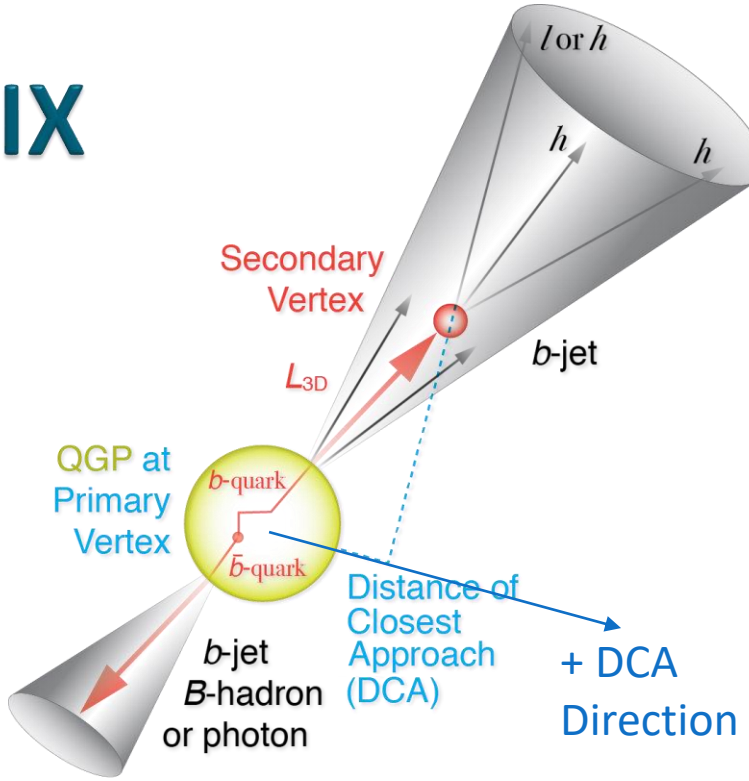
- Director's review – Apr/May
- DOE review – past summer



Tagging *b*-jets in sPHENIX

Exploring three leading methods for sPHENIX *b*-jets identification and crosscheck

- Multiple large DCA tracks
- Secondary vertex and kinematic fits
- *B*-meson tagging via semi-leptonic decay or direct invariant mass reconstruction
  - Need volunteer



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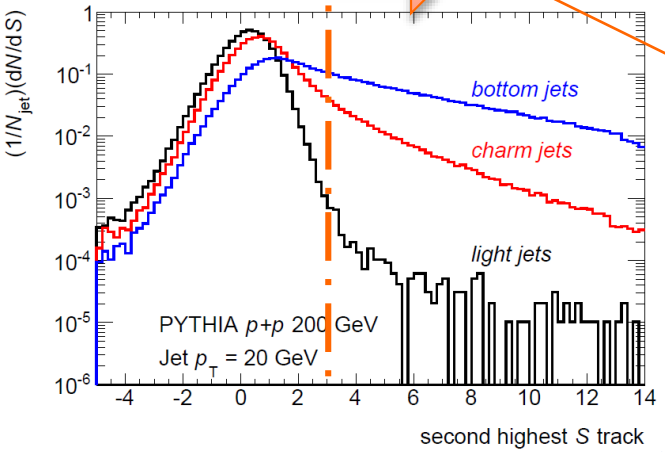
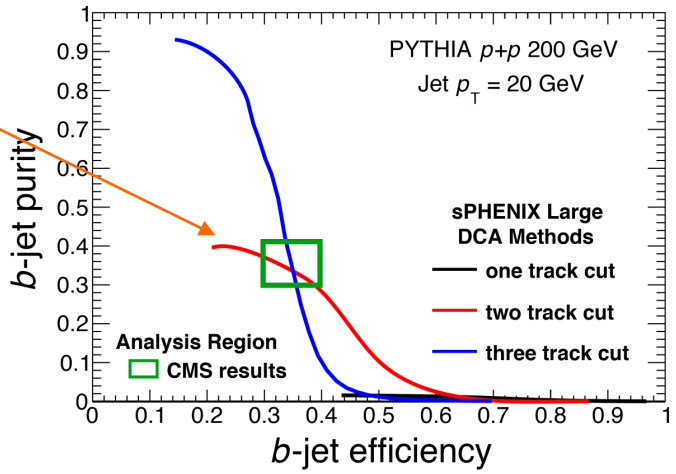
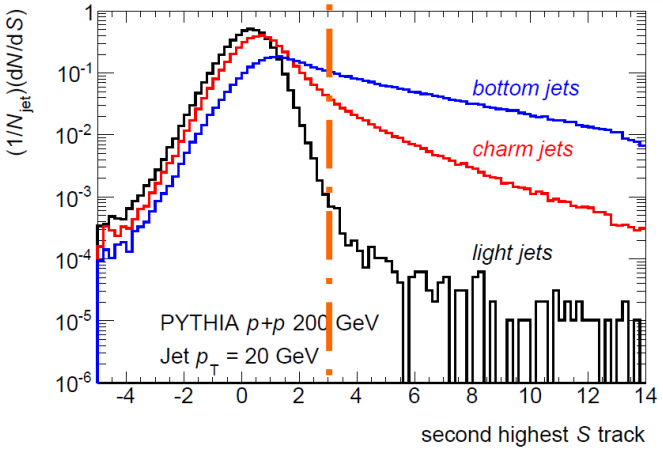


MIE-proposal projection (updated in G4 later slides)

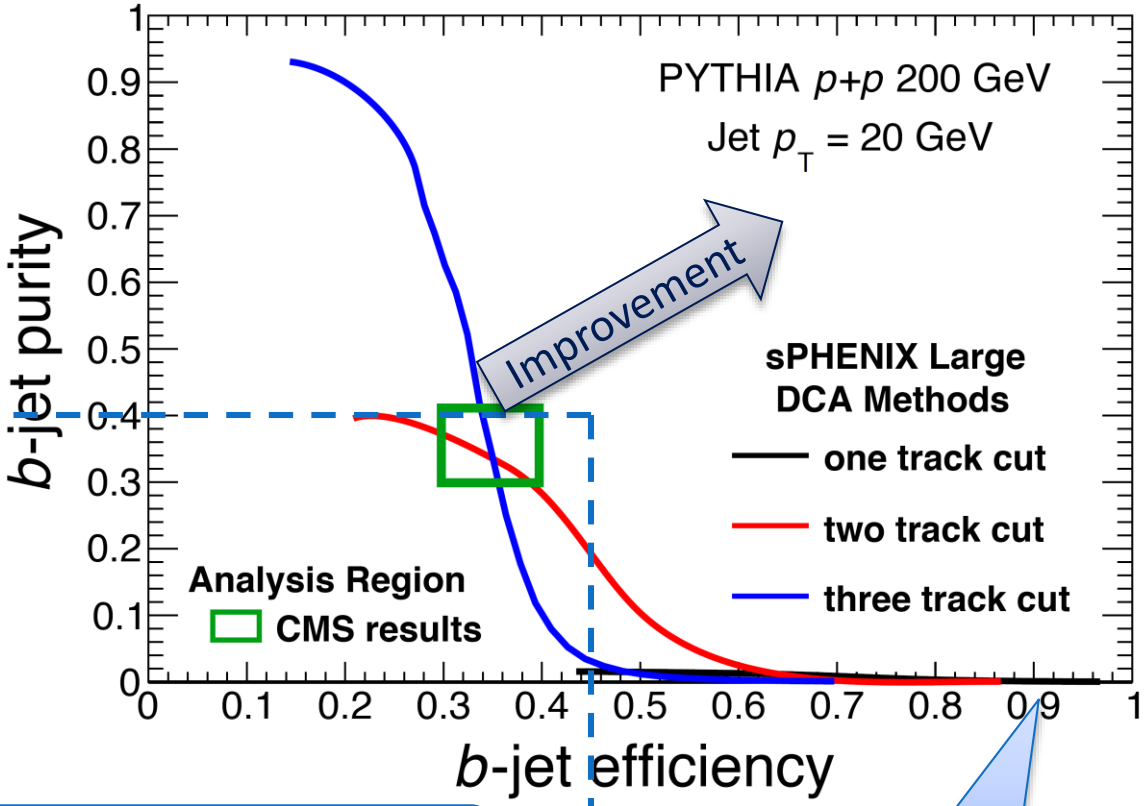


What affects performance curves

Cut



sPHENIX-proposal projection based on fast sim.
(already updated to Geant4 simulation)



Saturate efficiency at level determined by

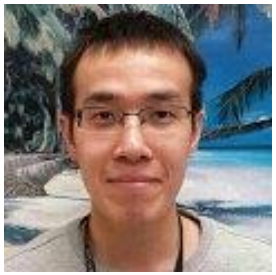
- Control light decay-background
- Fake high DCA (mismatching, alignment) → realistic sim.

Performance turn-on at primary particle's DCA peak
Efficiency improve w/ higher DCA precision and tracking eff.

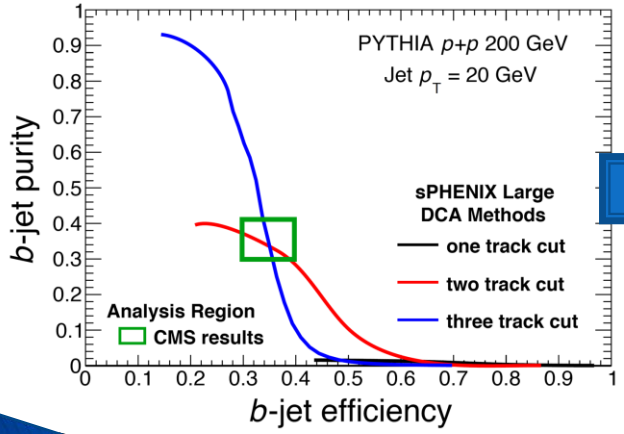
Initial b-jet fraction

Past activities:
b-jet tagging – High DCA track counting

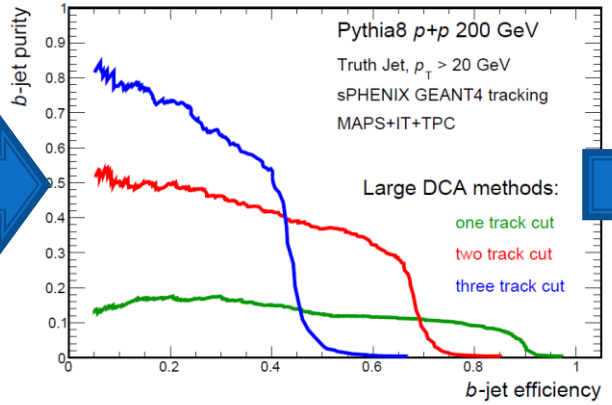
- Short history
  - Dennis and Haiwang implemented track counting tagger in the full Geant4 simulation
  - Haiwang produced projection plot in Geant4 simulation.
  - Systematically validating the Geant4-based track fit procedure, in order to optimize 3-D DCA and likelihood
- Next
  - Reevaluate in HI background with HIJING embedding
  - Optimizing cuts to suppress fake off-vertex tracks



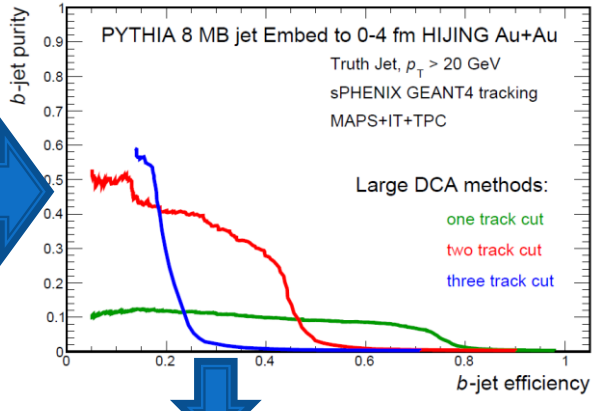
Fast sim in sPHENIX Proposal



Full Geant4 Sim



Exploring 3-D DCA in G4

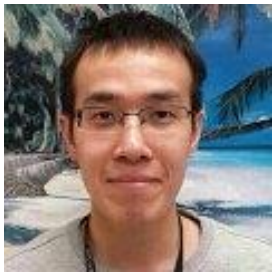


From Haiwang's talk
https://indico.bnl.gov/conferenceDisplay.py?confId=1926

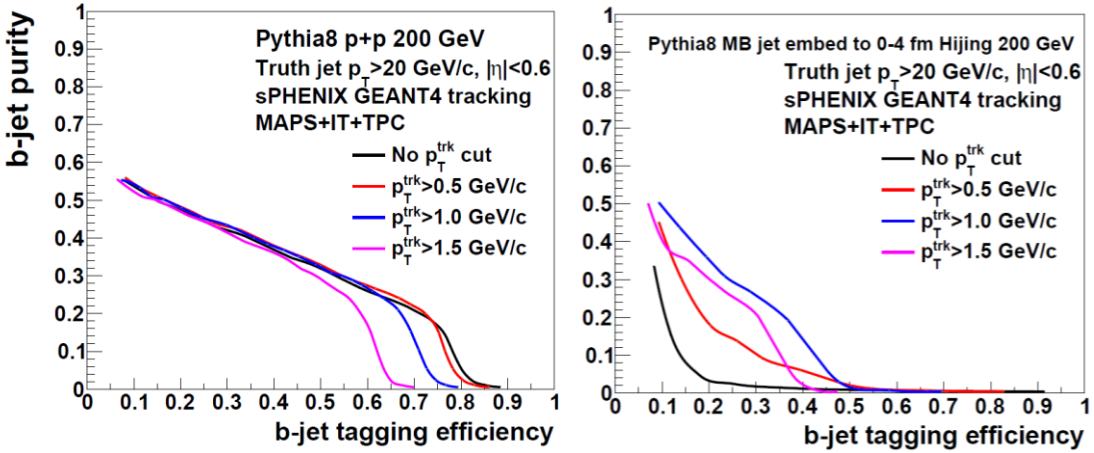
b-tagging performance in HI

Past activities:
b-jet tagging – Secondary vertex

- Short history
  - Haiwang developed new Kalman filter (GenFit2) with vertex finder integration (RAVE)
  - Sanghoon implemented Secondary vertex finder in jet
  - *p+p* performance plot used in tracking review
- Next:
  - Fixing a refitting inefficiency issue (further improve p+p results)
  - Reevaluate in HI background with HIJING embedding

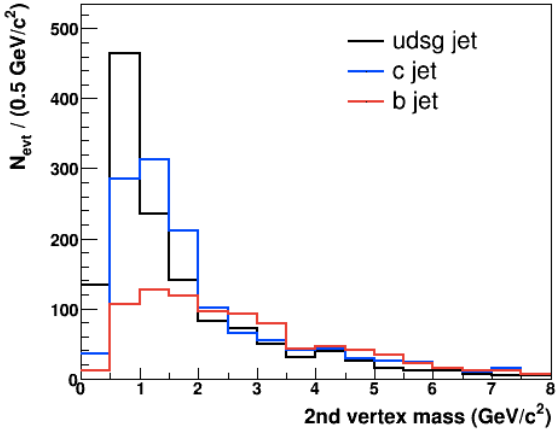


Secondary vertex *b*-tagger



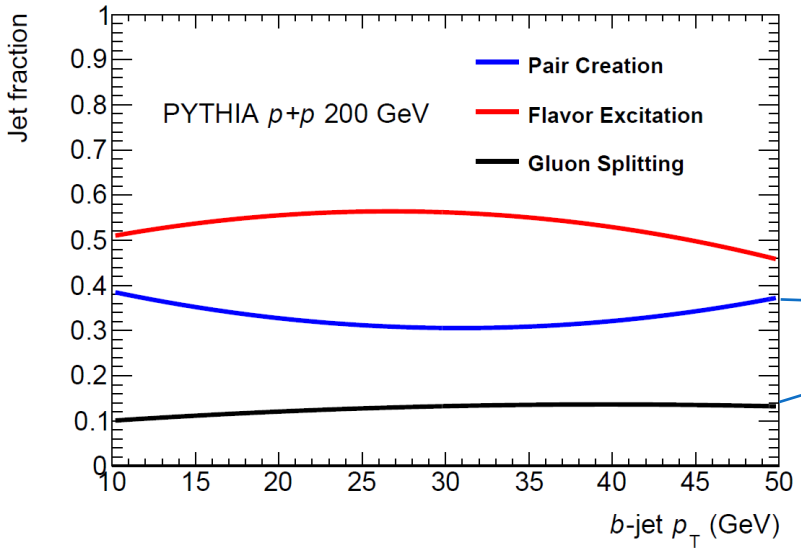
From Sanghoon's talk
https://indico.bnl.gov/conferenceDisplay.py?confId=1928

Secondary vertex kinematics fits
Data driven *b*-jet purity estimation

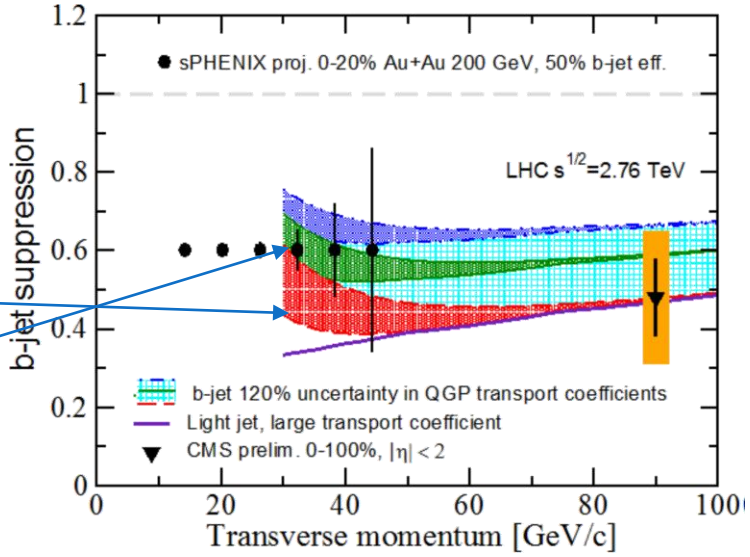


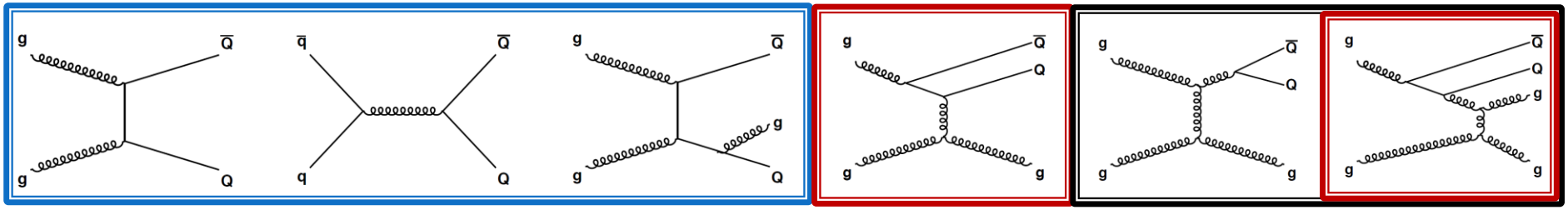
An vulnerability (opportunity) of HF-probes

sPHENIX scientific proposal



CMS, Phys.Rev.Lett. 113 (2014)
Phys.Lett. B726 (2013) 251-256

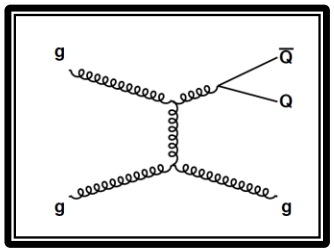


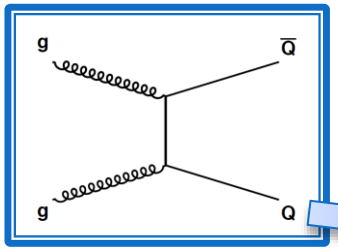


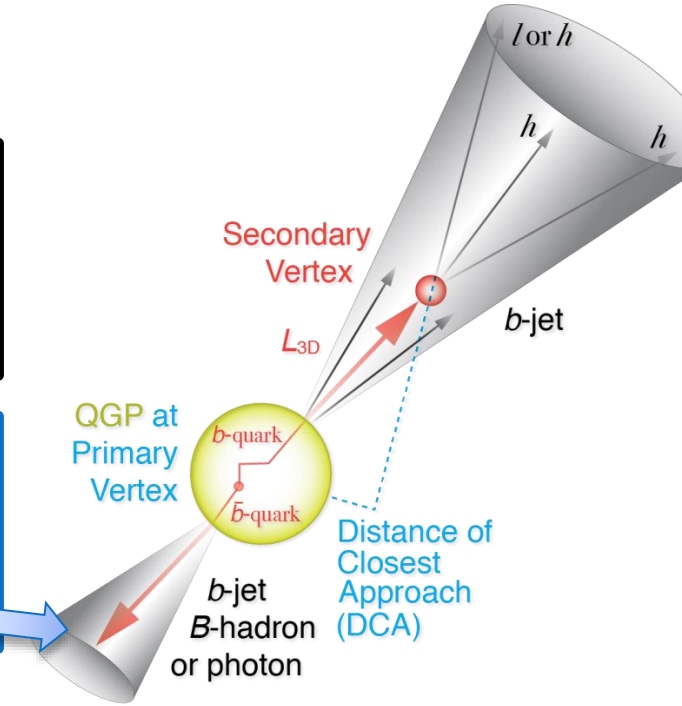
Lund String, Eur. Phys. J. C 17, 137–161 (2000)

b-quark jet selection: *b*-jet correlation

- Event topology to select *b*-quark jet
  - *b*-jet in correlation with opposite-going *B*-hadron, *b*-jet and photon
- sPHENIX provides good acceptance on *b-di*-jet and *b*-jet – non-prompt-*D* correlations
- Helps on purity of jet and *b*-tagging too
- Near term goals: fast-sim projections

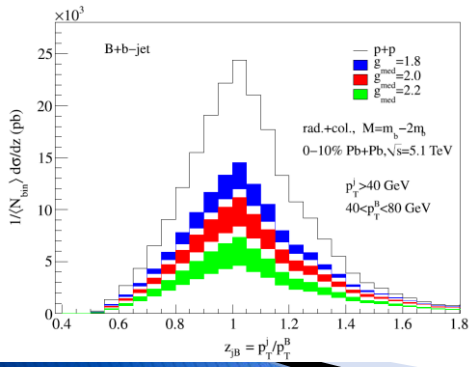






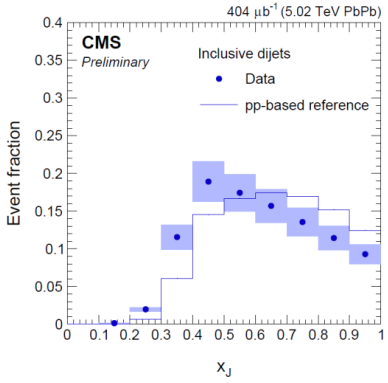
b-jet + *B*-hadron, model

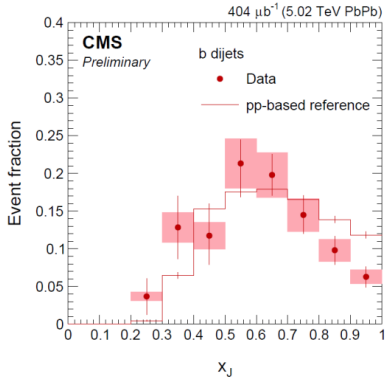
Physics Letters B750 (2015) 287–293



b di-jet, CMS 2016

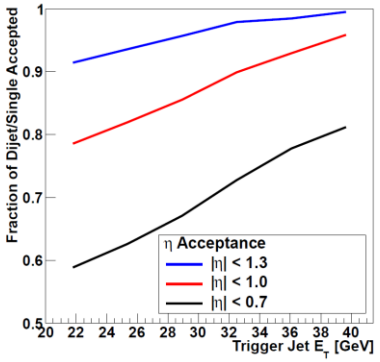
CMS PAS HIN-16-005



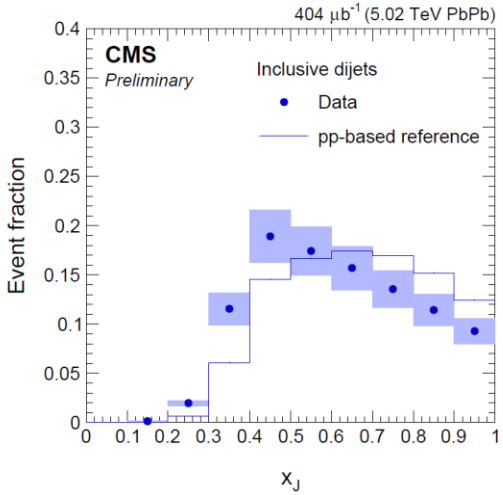


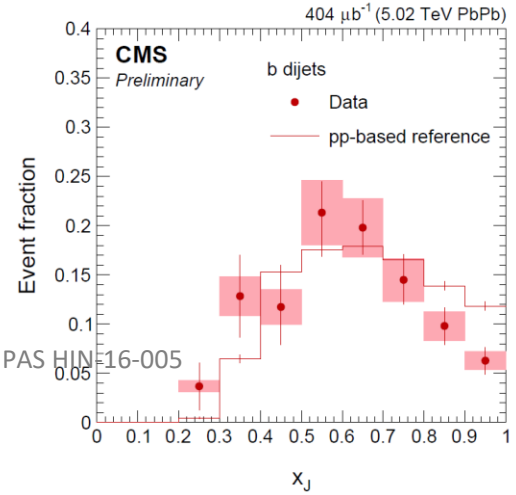
di-jet acceptance in sPHENIX

sPHENIX scientific proposal



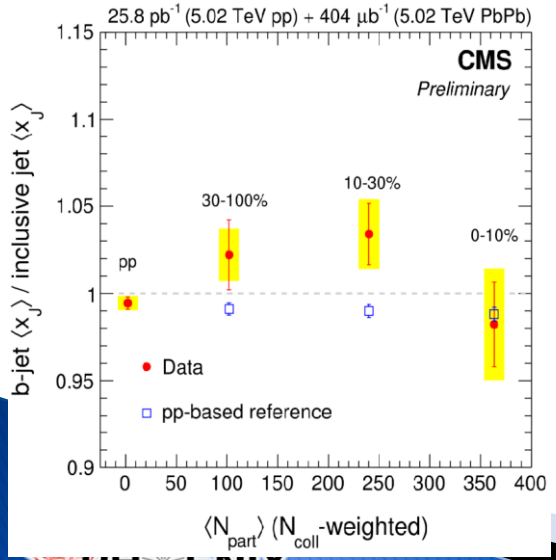
New studies for Di-b-jet asymmetry With reference to recent CMS TN



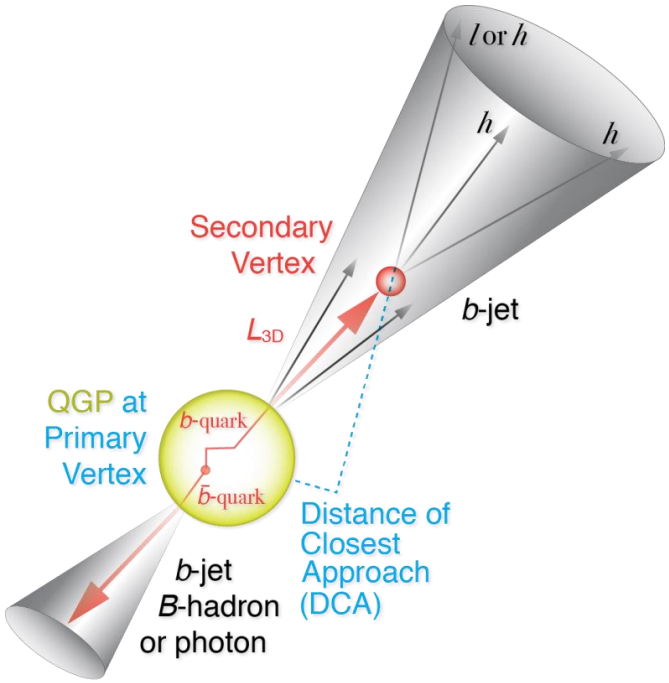


CMS PAS HIN-16-005

CMS-HIN-16-005

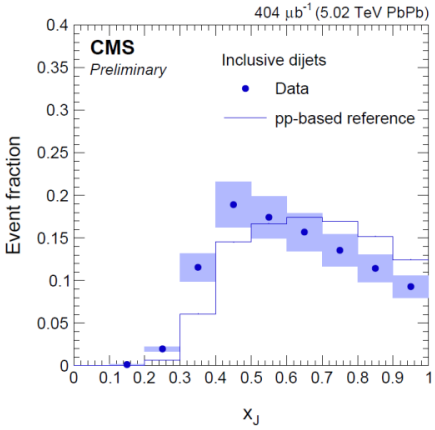


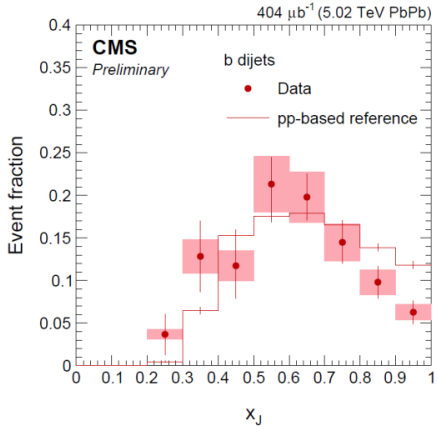
sPHENIX fast sim.



Work started in Jan-2017 workfest
sPHENIX di-bjet asymmetry,
- Darren McGlinchey (UCB)

Di-*b*-jet asymmetry: sPHENIX projection

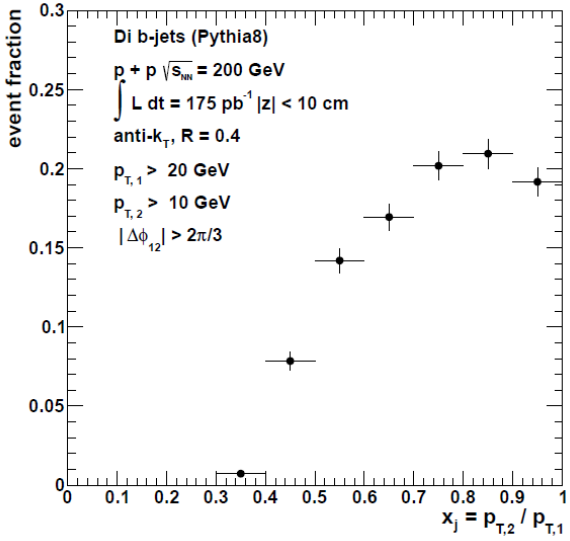


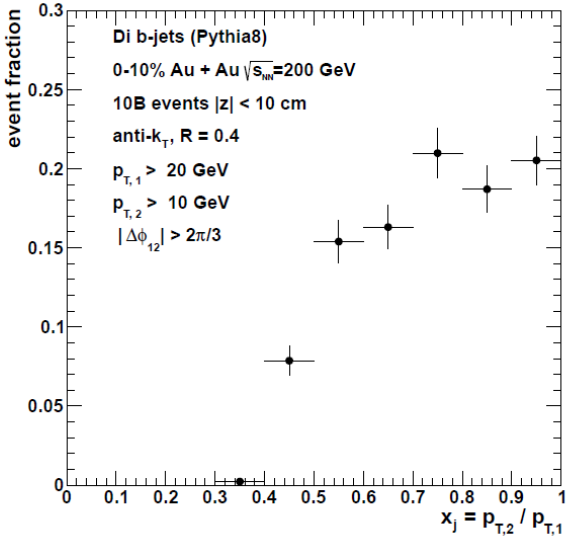


CMS-HIN-16-005, also Yen-Jie's talk July 2016

On-going sPHENIX projection

- By Darren McGlinchey (UCB)
- Pythia8 (HardQCDBBar)
- Fast sim. (truth jets)
- Assuming di-b-jet tagging perf.
  - Efficiency 50%
  - High purity (100%)
- R_{AA} = 0.6 assumed
- sPHENIX proposal lumi. (100B MB)



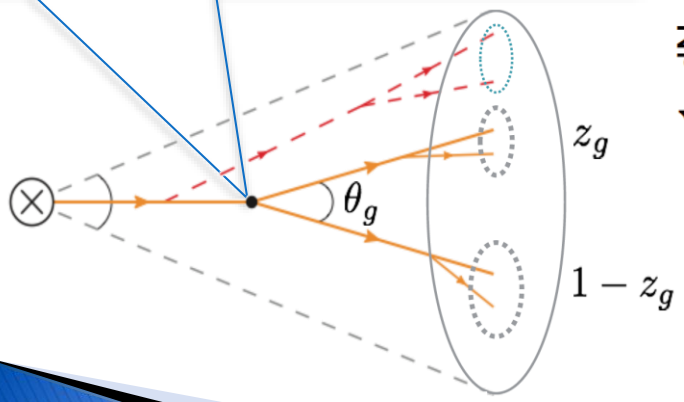


- For $p+p$ use integrated luminosity of $\int \mathcal{L}_{pp}\, dt = 175\ \mathrm{pb}^{-1}$
- For 0-10% Au+Au use $n+n$ equivilent luminosity of $\int \mathcal{L}_{nn}\, dt = N_{evt}^{AuAu} * \langle N_{coll} \rangle / \sigma_{nn} = 10\mathrm{B} \times 962/42\mathrm{mb} = 229\ \mathrm{pb}^{-1}$

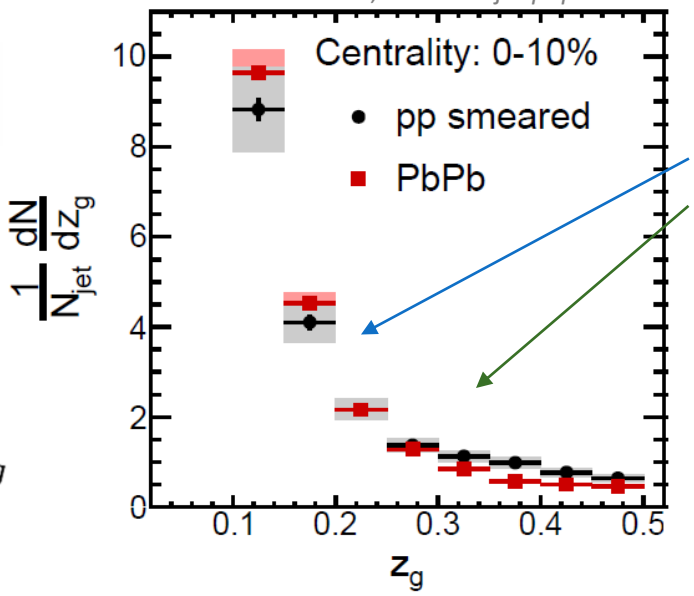
More ideas on *b*-quark jet selection? Jet structure tools

- Jet structure tool developed in HEP adapted in HI field
- Jet grooming observable z_g to separate *b*-quark jet and $g/q \rightarrow b\bar{b}$ jet?
- Mid-term goals: in collaborate with JS TG in developing grooming tools – volunteer welcomed!

Earliest splitting:
More symmetric for $g/q \rightarrow b\bar{b}$ jet?



CMS-PAS-HIN-16-006, inclusive jet *p*+*p* 5.02 TeV

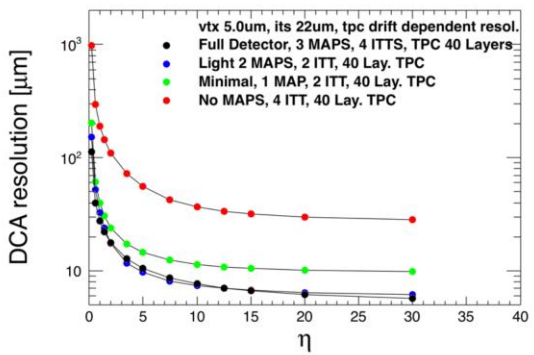


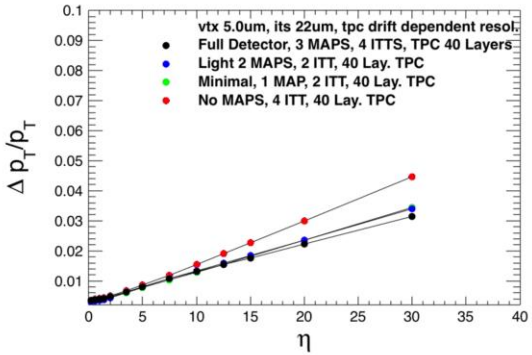
- *b*-quark jets ??
- $g/q \rightarrow b\bar{b}$ jet ??

A+A Modification would enhance z_g~0.5 (i.e. $g/q \rightarrow b\bar{b}$ less suppressed)?

From Christof R. https://indico.bnl.gov/conferenceDisplay.py?confId=2683

Alternate Detector Configurations



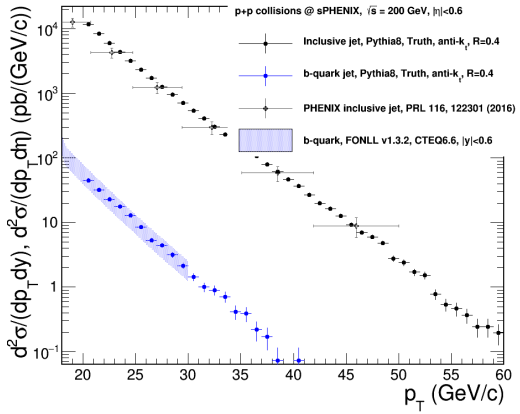


- Alternate detector configurations
  - Default -> 3 MAPS Layers, 4 ITT Layers, 40 Layers TPC
  - Light-> 2 MAPS Layers, 2 ITT Layers to save material budget
    - Slight performance advantage below 10GeV due to lower material budget
  - Minimal -> 1 Maps Layer, 2 ITT Layers, 40 Layers TPC
    - Significant performance decrease (remember 95% hit efficiency per layer)
  - No Maps
    - Likely death sentence for Heavy Flavor program…

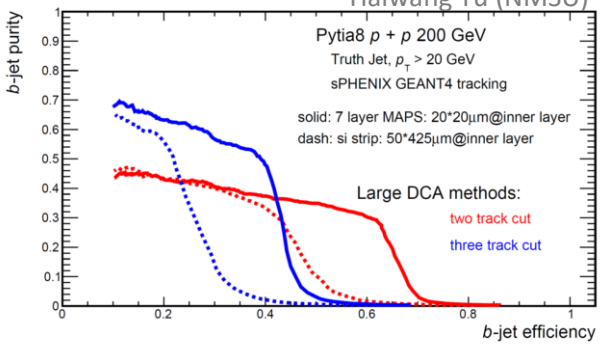
Christof Roland 8 sPhenix Simulation Meeting Mar 07 2016

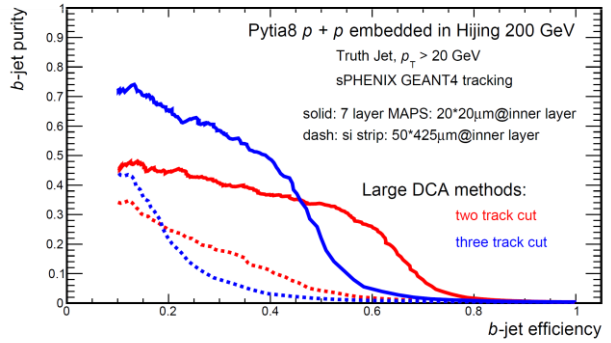
Detector requirement on MAPS/MVTX

- Caveats: there are trade-offs between tail/efficiency/DCA. Important final check is b-jet tagging performance working point: reaching 40% efficiency and 40% purity.
- Low fake high-DCA tail background
  - *b*-jets are rare (0.1%-1%) object identified via displaced vertex, therefore sensitive to rare large-DCA fake track background.
  - The working point of B-jet tagger is few-sigma above DCA peak, and
  - Possible specification: true large DCA track/fake large DCA track > 1:1-1:few for DCA tail integrated from 2-sigma to 1mm
- Tracking efficiency
  - Efficiency for multi-track tagging algorithm is sensitive to (tracking efficiency)^N
  - Possible specification: Require 60% (HFT KPP) – 75% (HFT UPP) single track efficiency p_T>1 GeV/c
- DCA
  - B-jet DCA requirement is relatively moderate
  - Requirement: DCA<100 um @ p_T>4 GeV/c (sPHENIX proposal)
- DAQ output event rate
  - Statistical limited measurement
  - B-jets are jet-structure study based on inclusive jets, require large jet-sample rate
  - Requirement: 15 kHz trigger rate to match sPHENIX DAQ



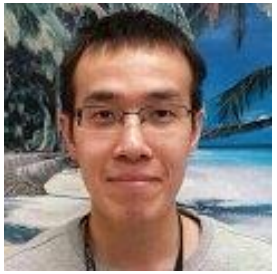
Haiwang Yu (NMSU)





Jin & Xin

b-jet tagging – High DCA track counting Update in HIJING embedding:



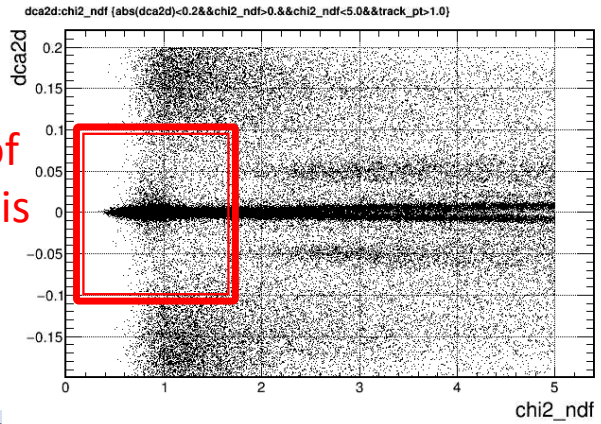
- Haiwang Yu (NMSU) initiated the study by embedding pythia-8 MB jets into 0-4 fm HIJING background, then go through full tracking Geant4 simulation and reconstruction
- Two configuration in study
  - Cylindrically modelled MAPS + INTT + TPC (target configuration)
  - 7-layers of MAPS (Same MAPS inner tracker + MAPS outer tracker) as reference of ultimate tracking configuration of very low fake tracking rate but same physics background.

MAPS + INTT + TPC, p_T>1 GeV/c

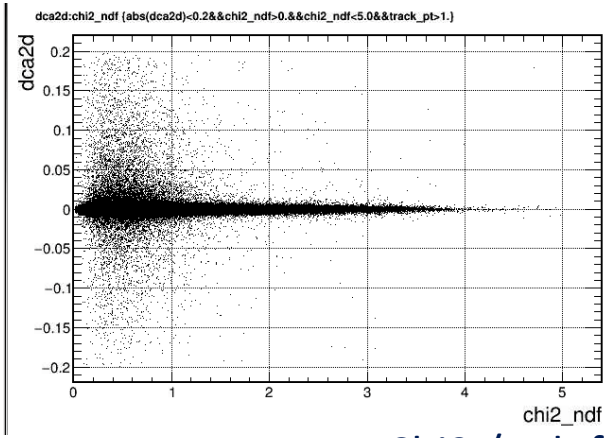
7-layer MAPS, p_T>1 GeV/c

DCA_2D (cm)

Region of analysis

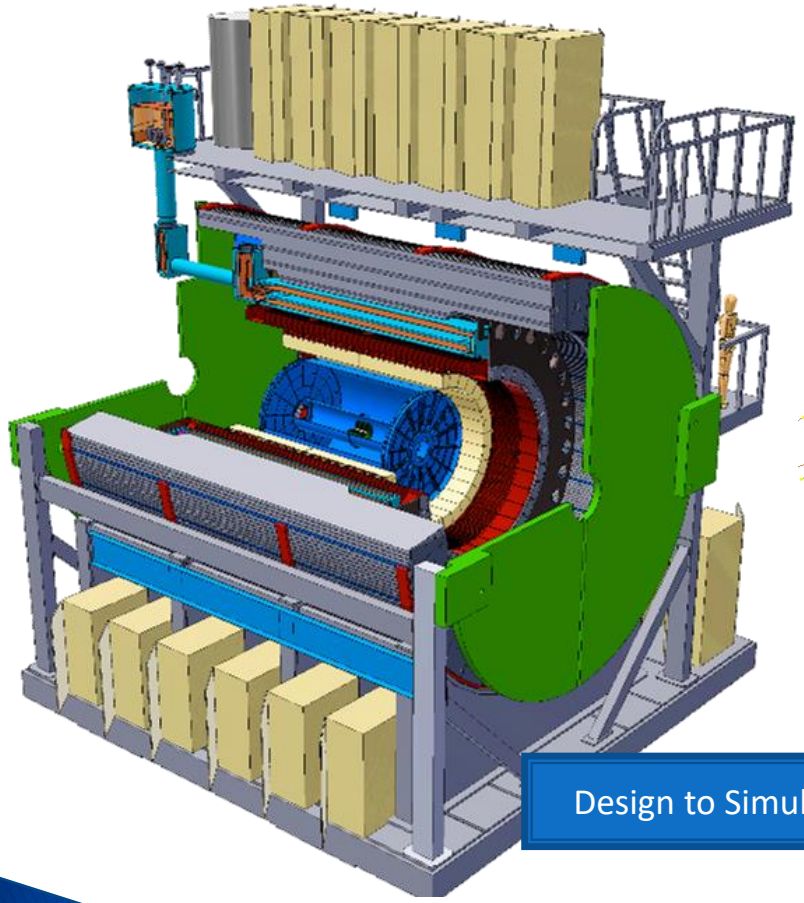


Chi2 / ndof



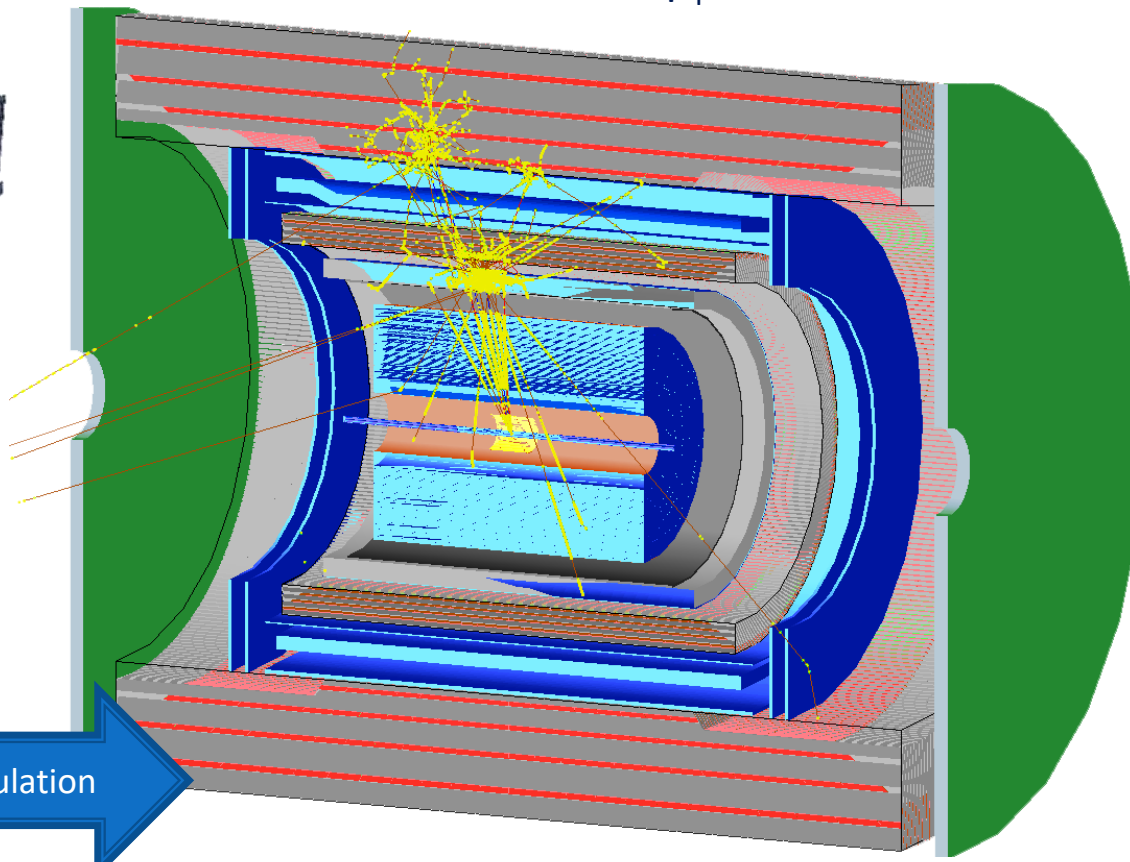
Chi2 / ndof

b-jet simulations, drawing to Geant4



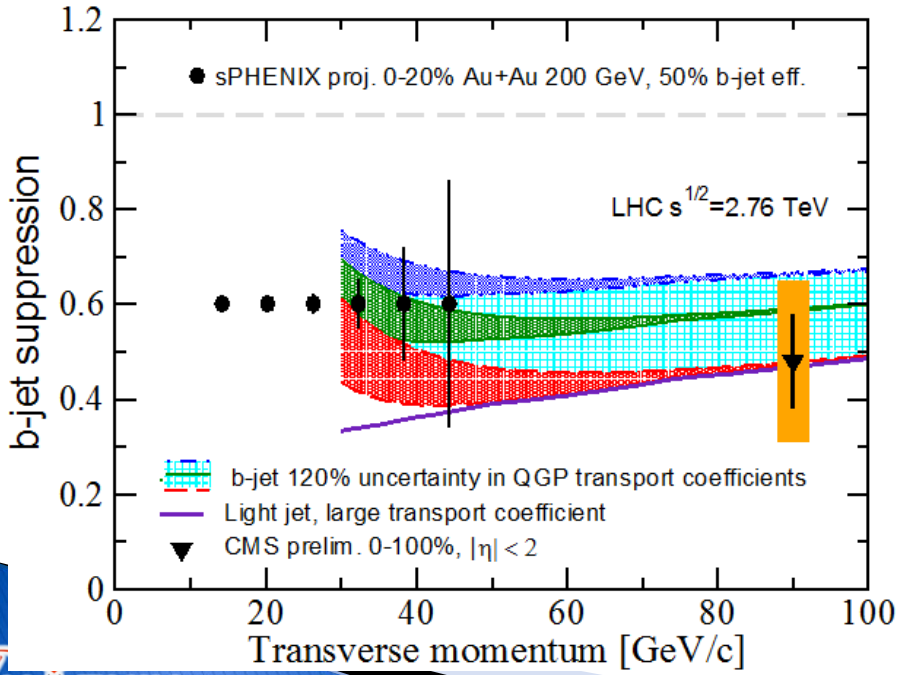
Design to Simulation

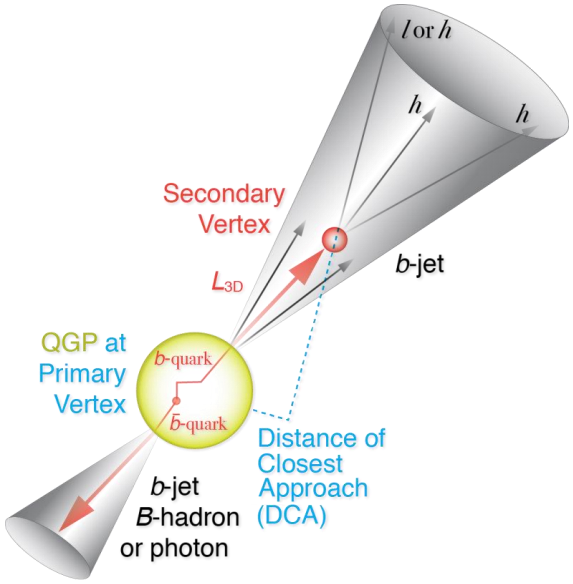
sPHENIX Geant4 simulation of p_T=30 GeV/c B^+-hadron



Luminosity counting

- Current RAA plot assumed 200B MB Au+Au in |z|<10cm
  - 100B MB Au+Au in |z|<10cm assumed for sPHENIX proposal
  - 200B MB Au+Au in |z|<10cm following updated CAD projection
  - Will follow the final luminosity number determined by collaboration for QM17 - Gunther
- For MAPS proposal, we need updated model R_{AA} for RHIC energy



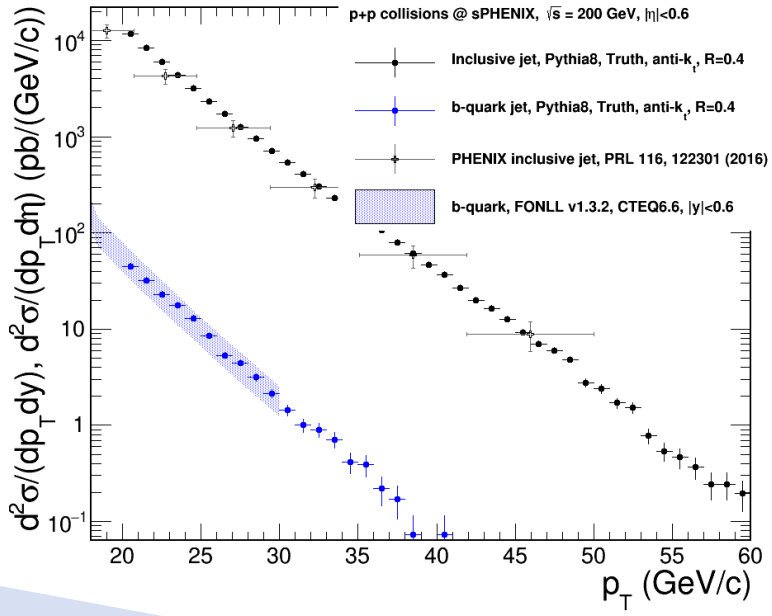


Simulation resources

- Currently we separate jet and b-tagging simulations to help speed up simulation. Need to verify factorization in the next stage
- Simulation setup used in analysis:
  - Tracking simulation in p+p in MAPS+IT+TPC (few minute / event)
  - Tracking simulation in HIJING + embedding for 7-layer MAPS (few minute / event, used for initial tunings) and for MAPS+IT+TPC (1-hour / event, use for performance plots)
- In developments
  - Silicon detectors in ladder geometry <- make available soon?
  - Pile up simulation <- make available soon?
  - TPC distortion corrections

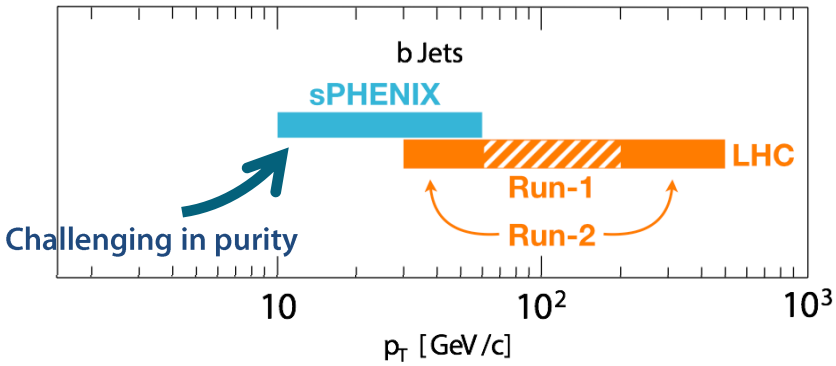
Jet flavor definition tools

- Unifying truth definition and jet sample generations
  - Based on Dennis' work defining a truth tagging module run on MB events to synchronize *B*-jet definition and yield between analyzers
  - Two options provided in defining truth jet by matching *b*-quark in jet (CMS definition) or by matching *B*-hadron in jet (proposal definition)
  - Available on GitHub: https://github.com/sPHENIX-Collaboration/analysis/tree/master/HF-Jet/TruthGeneration
- In collaboration with TS TG: Plan to be generalized to light-parton tagging and parton interaction channel categorizations
- Mid-term goal: cross checked with data and NLO generators

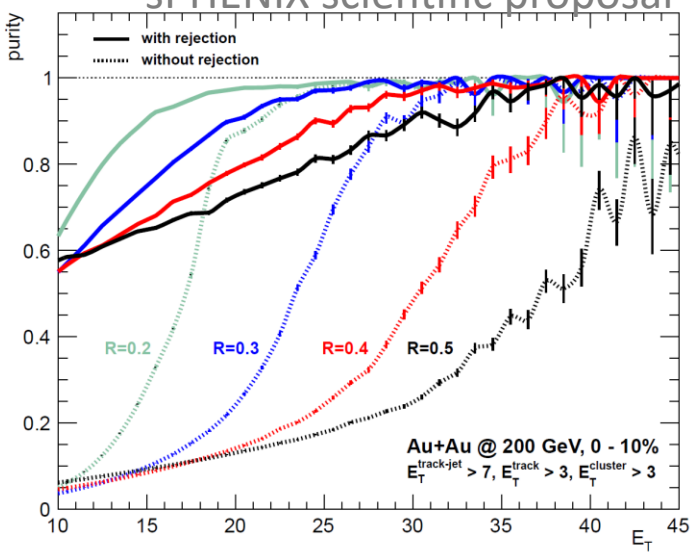


Jet finding and fake rejections

- HF-jet are based on jet, relying on jet finding development lead by JS TG
  - Emphasis on purity and reach to lowest-possible-p_T jet, where mass effect is maximized
  - No statistics for *b*-jet beyond $p_T > 50$ GeV/c
- HF-jet specific: response in detector for *b*-favored jet, unfolding and media modification
  - Require join study with JS TG in term of experience and toolkit developments



sPHENIX scientific proposal



Cross section from pythia8